Matched Field Tomographic Inversion for Geoacoustic Properties

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LONG TERM GOALS

The geoacoustic properties of the ocean bottom, including sound speed profiles, densities, attenuations and sediment layer depths, have a significant effect on sound propagation in shallow water. The long term goal of this work is to develop a new tomographic inversion method based on matched field processing of broadband data for estimating geoacoustic properties over an extended region of the ocean bottom.

OBJECTIVES

Matched field tomographic inversion is a relatively new approach (Tolstoy, 94) that is specifically designed for rapid, high resolution estimation of ocean bottom properties. The technique makes use of multiple vertical line arrays, and extends the MF inversion method to 3-D anisotropic environments, i.e. variability in depth, range and cross-range. An experiment to obtain acoustic field data at a multi-array system was successfully carried out using broadband sound sources in the Haro Strait Primer Experiment in June 1996. Initial analysis of the data for estimation of local geoacoustic properties has been reported previously (Chapman et al., 1997). The objectives of the present study are to develop an approach for using multiple array data to invert geoacoustic parameters in range-dependent environments, and apply the method to the Haro Strait data.

APPROACH

An extensive broadband data set was collected in the Haro Strait Primer experiment, using light bulbs and continuous wave tones as sound sources (Chapman et al., 1997). The first step in investigating the general tomographic inversion problem was to develop a method based on waveform matching for inverting broadband data. The method is based on ray theory to calculate replica fields in a range-dependent environment. The ray travel time data are used to localize the experimental geometry, and the full field data are used to invert the geoacoustic parameters. A novel pairwise matched field processor was investigated for use in the inversion (Frazer, 1998). The pairwise processor is not sensitive to mismatch in the source waveform, and is expected to improve inversion performance. Two approaches were tested for using the information from multiple sources and arrays: first a step-wise process that inverted the parameters separately in segments of the environment, and a second process that inverted the data from all sources and arrays altogether. Simulations were designed to compare the performance of each approach for multiple source/single array geometry, and for vertical slice tomography using two vertical arrays. In parallel with the ray-based inversions, inversions using parabolic equation (PE) fields are also being investigated for the range-dependent environment. This approach is being applied to the multi-tone data obtained in the Haro Strait experiment.

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WORK COMPLETED

Work was completed on comparing the performance of the pairwise matched field processor with other processors such as the Bartlett and minimum variance processors. A ray theory propagation model (HaroRay) was developed for the experimental environment at Haro Strait and applied to invert the array/source locations using the travel time information in water column ray paths (Pignot and Chapman, 1999). The ray model was also applied to invert the range dependence of the geoacoustic parameters for the single/source multiple array geometry.

Simulations were completed to investigate the performance of two arrays to invert the geoacoustic parameters in a range-dependent environment. The inversion is based on the ray propagation model, and uses the pair wise matched field processor for broadband data.

Multi-tone continuous wave data were also recorded in the Haro Strait experiment. These data were processed to obtain spectral components at six frequencies for use in an inversion based on the PE. Simulations were designed and completed to compare the.

RESULTS

A paper describing the freeze bath method for inversion of geoacoustic parameters was published in the Journal of the Acoustical Society of America (Jaschke and Chapman, 1999). The method makes use of the heat bath algorithm for simulated annealing. However, unlike simulated annealing, the system is not 'cooled' to an optimal solution. Instead, the process is paused at a temperature near the annealing point, and the distribution of possible models that provide a good fit to the acoustic field data is sampled at that temperature. The method also determines an optimal set of independent parameters, based on the covariance matrix of the sampled models, and adjusts the annealing temperature adaptively to account for parameters with different sensitivities. The method is thus capable of determining correlations between geoacoustic model parameters, and providing an estimate of the error in the estimated parameter values. The method was applied to the Haro Strait data for a single light bulb and one of the arrays (Chapman and Jaschke, 1998). Estimated parameter values for the sediment sound speed and layer thickness were consistent with ground truth data, and the estimated (a posteriori) distributions showed which of the model parameters could be estimated reliably.

A range-dependent inversion method was developed for inverting the data from multiple light bulb sources deployed radially from a vertical line array. The process involved several stages: first, the identification of the acoustic path for each component of the light bulb signals; and subseqently, the inversion of travel time and amplitude information from each of the bulbs. An efficient, automatic algorithm was designed to identify the multipath signals. The environment was segmented into sections corresponding to the locations of each of the light bulbs. The geoacoustic properties in each segment were inverted in turn, starting with the segment closest to the array, and using new data for each segment. The inversion method used a straightforward Monte Carlo search combined with a local downhill simplex algorithm. The method proved to be efficient and accurate in simulations for the broadband data for a synthetic Haro Strait environment. A paper was submitted to the Journal of the Acoustical Society of America (Pignot and Chapman, 1999).

In parallel with the segmented inversion approach, vertical slice tomography was also tested in simulations to invert range-dependent geoacoustic parameters. The first scenario used a single vertical array and multiple sources in different planes. The inversion was based on the ray theory replica fields, and used the new pairwise matched field processor in a hybrid global search process (genetic algorithm and simplex method). The simulated environment was divided into cells, and the geoacoustic parameters for each cell were inverted simultaneously. The simulation results indicated that the multi-source cost function provided improved inversion performance, compared to single source-single array inversions that were carried out for each source independently. The reason is evidently due to the reduction of sidelobes (local minima) in the multi-source inversion. A paper describing the results was submitted to the Journal of Computational Acoustics (Corre et al, 1999a). A second scenario that uses two vertical arrays and multiple sources in the plane of the arrays has also been investigated.

In order to apply the inversions to the Haro Strait broadband data, a linearized inversion was developed for localization of the array elements. The method makes use of relative travel times for direct path and bottom reflected signals received at the array, assuming that the bathymetry is known. The approach was applied to localize the elements of two of the vertical arrays simultaneously, using data from two sources (Corre et al, 1999b). Results indicated that one of the moored arrays had moved substantially from its estimated position at deployment, in a direction consistent with the known currents at the site.

Initial results were obtained for simulations using multi-tone signals and PE replica fields for inversion of geoacoustic properties in a range-dependent environment (Viechnicki and Chapman, 1999). Work is in progress to design an efficient approach for inversion of the continuous wave data from Haro Strait.

IMPACT/APPLICATIONS

The Haro Strait experiment was the first opportunity to investigate the concept of geoacoustic matched field tomography with real data. To date, several new results have been obtained in developing an approach for inverting the multi-array data. The freeze bath inversion method provides a meaningful error measure for the inverse problem, as well as the estimate of the optimum value. This approach holds interest for seismic as well as acoustic inversion. The pairwise matched field processor has been shown to provide improved performance compared to the standard processors. The improvement is due to its insensitivity to the source waveform. The vertical slice tomographic inversion method provides an efficient means for estimating geoacoustic properties over an area. Its improved performance is due to the increased amount of information (from the multiple arrays) in the cost function.

TRANSITIONS

The broadband light bulb data from the Haro Strait experiment were used by collaborators from MIT in an ocean acoustic inversion of the sound speed profile over the are enclosed by the arrays (Elisseeff et al, 1999), and by researchers at the Defence Research Establishment Atlantic in an investigation of the source level of light bulb implosions (Heard et al, 1997). The Haro Strait data have been provided to two other investigators: Dr. Alex Tolstoy has used the Haro Strait concept in her simulation work, and intends to use some of the broadband data in her investigations of geoacoustic inverse methods that have been funded by ONR; Dr. Eliza Michalopoulou has received samples of the light bulb signals.

RELATED PROJECTS

This work on geoacoustic inversion is related to several other projects currently funded by ONR; I have had discussions with investigators in each project to describe the results of the Haro Strait experiment. These projects include: the Yellow Sea experiment (Peter Dahl, APL, Washington); the SHELFBREAK Primer experiment (Jim Lynch, WHOI and Kevin Smith, NPS); and the geoacoustic inversion investigations of Mediterranean Sea data by Alex Tolstoy and Peter Gerstoft.

Geoacoustic inversion using light bulb sound sources was used in the Santa Barbara Channel experiment in April 1998. I designed the deployment geometry at the request of the project leader, Dr. Newell Booth.

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